A Capstan for Deep-Sea Hoists

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A novel capstan design has been studied and developed at NRL. The capstan consists of two identical slotted cylindrical drums which rotate intermeshed on axes which are both offset and canted with respect to each other. The operation of this capstan is somewhat similar in principle to that of the winding reels which were originally employed in the textile industry. However the NRL version, through an arrangement of eccentric journals, is capable of continuously winding and laterally advancing a heavily loaded cable in such a manner that it aligns itself on the capstan and consistently follows the same path. Test results obtained using models indicate such a capstan meets requirements for use as the traction member of a deep-sea hoist.

INTRODUCTION

In the field of underwater technology there is an increasing demand for improvements in deep-sea research equipment. Included among such equipment is a high-load-capacity deep-sea hoist, which is capable of storing long lengths of cable. When a long cable supporting a heavy load is wound onto a drum in a multitude of layers, the shear loads exerted against the side flanges, as well as the compressive loads about the drum shell, may become exceedingly high. Complicated structural problems arise when designing a hoist of this type, since long cables ne[illegible]ate many layers of windings on the drur[illegible] inspection, one might deduce that these loads may be obtained directly from the summ[illegible]ion of forces exerted by each cable layer; however, thi[illegible] is not the case. It is not theoretically [illegible]ortion of the stress in each layer is [illegible] total load; therefore computat[illegible] distribution on the drum b[illegible] [illegible]mes intractable.

If the functions of haul[illegible] were accomplished by [illegible] shown in Fig. 1, the as[illegible] problems are more eas[illegible] a two-stage hoisting system [illegible] cable to be stored under greatly reduced tension. This is advantageous, since it reduces the drum stresses and allows the use of a lighter, simpler storage drum. Low-tension cable storage also permits several different sizes and shapes of cable to be handled with only few modifications or adjustments to the traction unit. The components of a two-stage hoisting system can be arranged in such a manner that the overall center of gravity of the hoist system could be substantially lowered. This

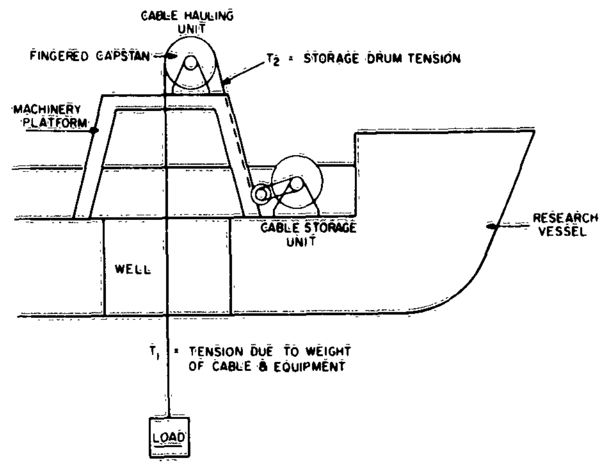

Fig. 1 - Shipboard arrangement of hoist components

is a desirable consideration for shipboard application. The storage drum, with its tons of cable, could be located at some remote position below decks. The complexity of this system necessitates somewhat greater space requirements and cost; however these two disadvantages are offset by the aforementioned advantages.

The two stages of the hoist are the cable hauling unit, of which the capstan and its driving gear are members, and a cable storage unit, which consists of a storage drum, its driving gear, a levelwind, and a constant tensioning device. This tensioning device must maintain a predetermined back tension in the cable between the capstan and the storage drum. The capstan must develop sufficient traction to provide the required ratio between the load tension and the desired storage tension. This tension ratio is found from the equation

$$T_1/T_2 = e^{\mu\theta}$$

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where T_1 is the tension on the load cable; T_2 is the storage tension, e is the base of the natural logarithms, μ is the coefficient of static friction, and θ is the angle of wrap. Additionally, the capstan must provide continuous cable hauling that is free of slippage and sideplay. To accomplish this, it is necessary to devise a capstan which is capable of laterally advancing the cable as it rotates.

DESCRIPTION

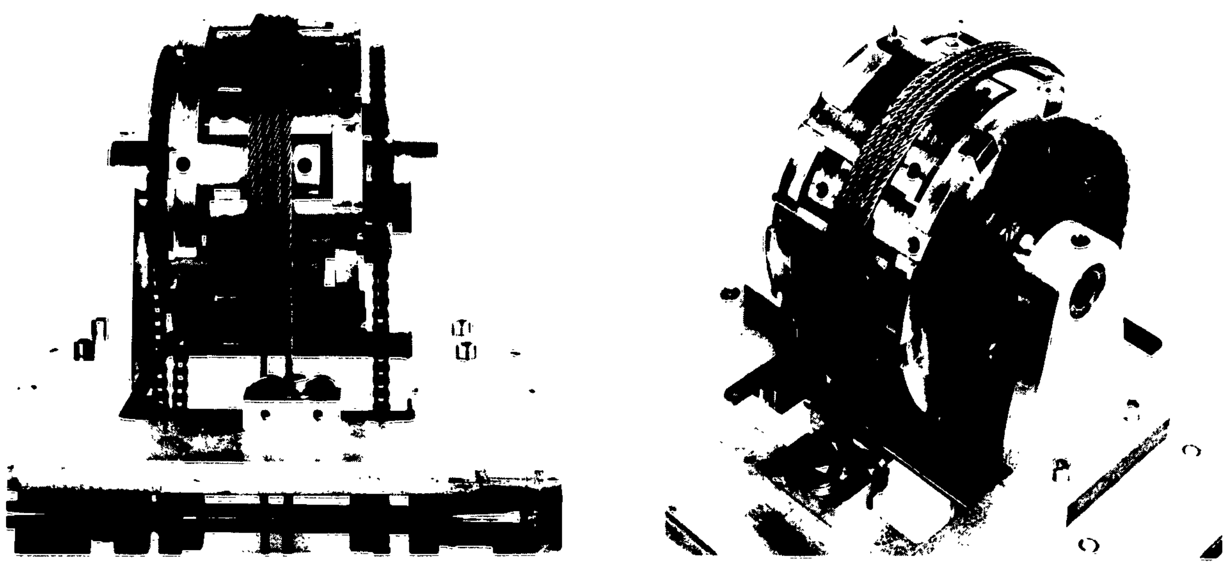
The NRL capstan (Figs. 2a and 2b) consists of two identical drums which are in essence, axially slotted cylinders. The two cylinders are mounted so that their bars intermesh, and the intermeshed units rotate essentially in the same space that would be occupied by one unit, on axes which are both offset and canted with respect to each other. Each slotted drum consists of two end disks connected by axially mounted bars. The capstan may be driven by only one drum. For greater efficiency and less wear, however, it would be preferable to apply an equal driving torque to both drums. Torque transmission may be by gearing, roller chains, or some other method by which the undesirable bar-to-bar contact between drums is avoided.

OPERATION

In general, the operation of this capstan is similar to that of the winding reels which were originally employed in the textile industry. The offset relation of the slotted drums causes the cable which is wound about the capstan to be carried for half the circumference of the capstan by the bar members of each drum. For each half revolution of the capstan, the bar members of one drum carry the cable. During the other half of the revolution of the capstan, the bar members of the other drum carry the cable. Thus, as the capstan rotates, an element of the cable is transferred from the bar members of one drum to those of the other, every 180 degrees. The canted relation of the bars causes the cable to advance laterally across the capstan.

The result of these operations is to advance the cable laterally across the capstan in a series of approximately helical turns. The pitch of the helix is determined by the angle between the canted axes of the drums.

To illustrate this operating principle consider Fig. 3, which shows the plan and cross-sectional views of the capstan. The drums are shown both canted and offset with respect to each other. Assume that the cable is moving from right to left. The cable first makes contact at point 1, which is on a bar of the upper drum (as seen in the sectional view). This drum is canted in such a direction that it pulls the cable laterally toward the other drum. As the cable leaves the upper drum and passes across the gap between the drums at right angles to the axis of rotation (point 4), it is transferred to the lower drum because the bar members of the lower drum now pass outside of the periphery of the upper drum. The lower drum will carry the cable during the next half revolution. Since the



(a) (b)

Fig. 2 - Two views of NRL capstan test model

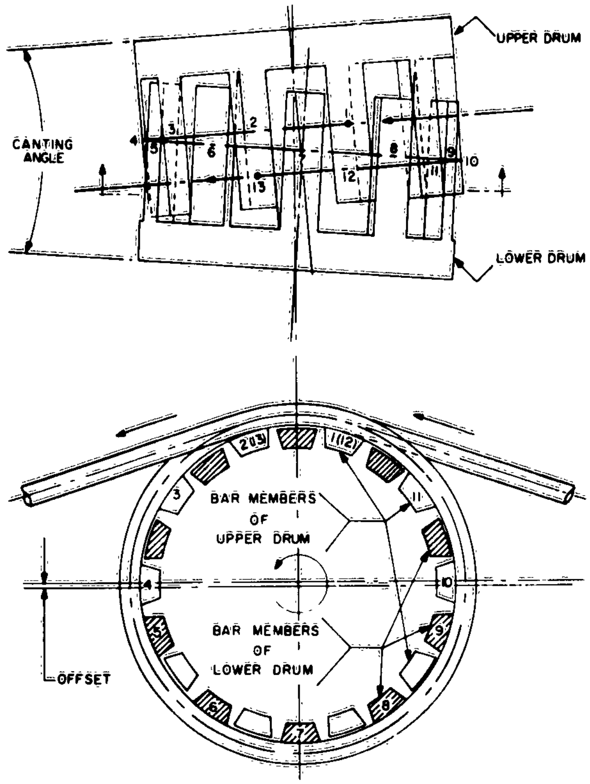


Fig. 3 - A schematic showing the path of an element of cable during one rotation of the capstan

drum is canted, it causes the cable to travel laterally in the same direction and at the same rate as before. After passing the horizontal axis (point 10) the upper drum again engages the cable and continues moving it laterally as it rotates (points 10 to 13). Neglecting relaxation, the cable motion is purely rolling action, free of slippage and sideplay. There are no unbalanced forces to cause this path to be altered. Each element of cable follows the preceding element throughout the same path.

This cable advancing process is reversible. Assuming the cable to be moving from left to right (Fig. 3), it first makes contact at point 13, which is located on a bar of the upper drum. As the drum rotates clockwise, the cable is pulled laterally toward the other drum, since the upper drum is canted in the same direction. As the cable passes the horizontal plane (point 10), parallel to the axis of rotation, it is transferred to the lower drum because the bar members of the lower drum are now passing to the outside of the upper drum. As before the cable is displaced laterally due to the canted relation of the drums. After being pulled through one-half revolution on the lower drum, the cable is transferred to the upper drum which engages the cable and moves it laterally until the cable leaves the drum at point 1. The reversibility of the process is an important requirement for hoisting applications. For proper operation of this capstan, the cable must be guided to the capstan in a path which is perpendicular to the axis of rotation of the drum it initially contacts.

DESIGN CONSIDERATIONS

The lateral displacement of the cable is directly proportional to the angle to which the drum members are canted. For the purpose of illustration, the cant angle is exaggerated in order to portray better the cable path across the drum. In actual practice however, this angle may be quite small. As an example, let us assume that a length of 1-inch-diameter cable is wound around a 48-inch-diameter capstan, as shown in Fig. 4. The minimum lateral displacement must be at least one cable diameter per revolution of the capstan. Then in a half turn of the capstan, the cable must advance a half cable diameter or ½ inch.

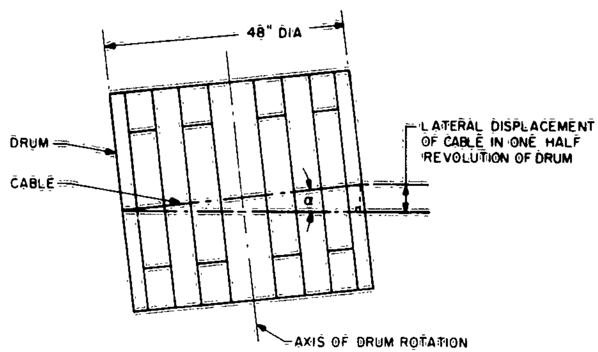


Fig. 4 - Lateral displacement effected by cant angle

The cant angle α for one drum is

$$\alpha = \sin^{-1}\frac{(0.5)}{(48)} = 0°36'.$$

Since the other drum must also be canted to laterally displace the cable during the other half revolution, the total cant angle $= 2\alpha = 1°12'$.

The offset must lie in a plane which is perpendicular to the plane in which the drums are canted, and it must be of sufficient magnitude to cause each drum member to engage the cable for only a half revolution. The minimum amount of offset required is equal to the product of the drum radius and the versine of half the angle subtended by the gap between the bars of one drum (this minimum is required to maintain clearance between the cable and the bars of the drum which are not to be contacted). Both the offset and cant angle limit the cross-sectional contours of the bars, since they obviously must be shaped to operate intermeshed, but free from mutual interference.

To obtain the desired action between drum members, eccentric journals, whose bearing faces are both offset and canted with respect to the mounting shaft, are employed. Figure 5 shows the arrangement of the journals. It should be noted that parts 1 and 4 are identical—as are parts 2 and 3. Parts 1 and 3 form a pair of bearing surfaces about which one drum rotates, while the other drum rotates about parts 2 and 4.

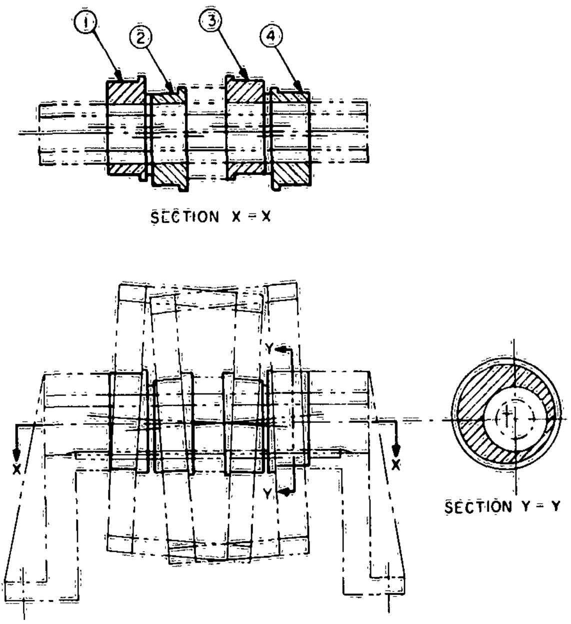


Fig. 5 - Arrangement of journals showing offset and cant

It is due to this arrangement of eccentric journals that the aforementioned cable-advancing principle may be applied to a high-load-capacity capstan. Heretofore, reels based on this principle were of the fingered-cantilever drum design. The inherent weakness of the cantilever design limits their use to low-tension winding applications, such as are found in the textile industry. However, in the NRL capstan the drums are much stronger because the bar members are rigidly supported at both ends.

The peripheral contour of the bar members also must be considered. It was observed that considerable wear results from action between the cable and the contact surfaces of the bar members when they are curved to conform to the drum radius, as shown in Fig. 6a. The wear is due to the sharp bending of the cable across the unsupported gap between the bars. This difficulty becomes negligible if the bars are shaped to provide a smooth transition from the radius of the drum to the chord between the bars. The correction may be determined by the ratio

$$S/S' = R/r_c \,.$$

Algebraic rearrangement gives the corrected radius r_c necessary for smooth transition (Fig. 6b).

$$r_c = \frac{S'R}{S} \,.$$

The diameter of the drums is determined by the minimum bending diameter of the cable. The length of the drums, however, need only be sufficient to accommodate the number of cable wraps required to produce the required tension ratio.

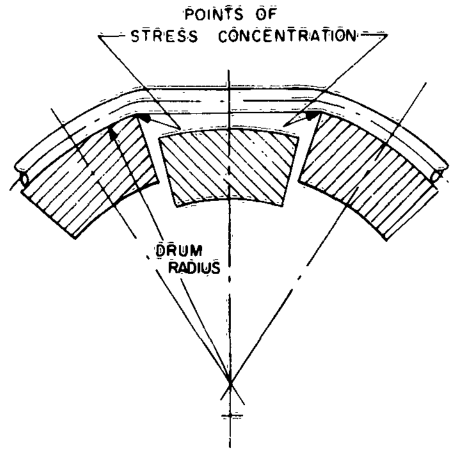


Fig. 6a - Bar members contoured to drum radius

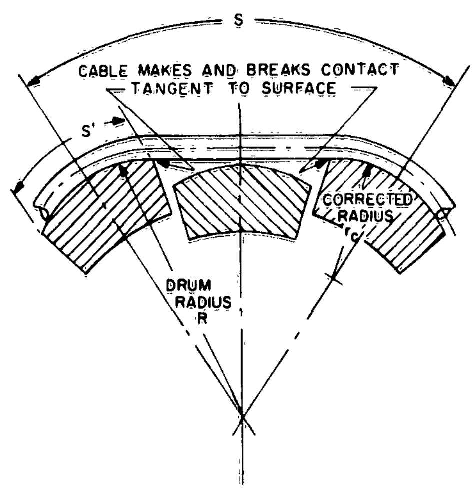


Fig. 6b - Bar members contoured to corrected radius

This may be determined from the equation

$$T_1/T_2 = e^{\mu\theta}.$$

As an example, assume that a long cable is tensed to 14,000 pounds (T_1), and that the tension in the cable to the storage drum is to be maintained at 200 pounds (T_2); then the tension ratio T_1/T_2 = 14,000/200 = 70:1. The coefficient of static friction for steel on steel (μ) is assumed to be 0.15. From these data the required angle of wrap (θ) is determined.

$$T_1/T_2 = e^{\mu\theta}$$

$$70 = e^{0.15\theta}$$

$$\mathrm{Ln}\ 70 = 0.15\theta$$

$$4.248 = 0.15\theta$$

$$\theta = \frac{4.248}{0.15} = 28.3 \text{ radians}$$

$$\theta = \frac{28.3 \text{ rad.}}{2\pi} = 4.50 \text{ wraps}$$

The results show that at least four and a half wraps of cable around the capstan are required to yield a 70:1 tension ratio; however, this must be confirmed since the coefficient of friction $\mu = 0.15$ is an assumed value which was taken from a handbook and may not be sufficiently accurate. By conducting a tension test using a scaled model of the capstan with steel cable, weighing scales (to measure maximum T_1 before slippage), and a set of constant tension springs (to apply tension T_2) as shown in Fig. 7, the data in Table 1 was obtained. Results of the tension test indicate 3½ wraps of cable yields only a 19.9:1 tension ratio and in order to obtain a 70:1 ratio another wrap, or 4½ wraps, is required. It therefore appears that the assumption of 0.15 as the coefficient of friction is acceptable.

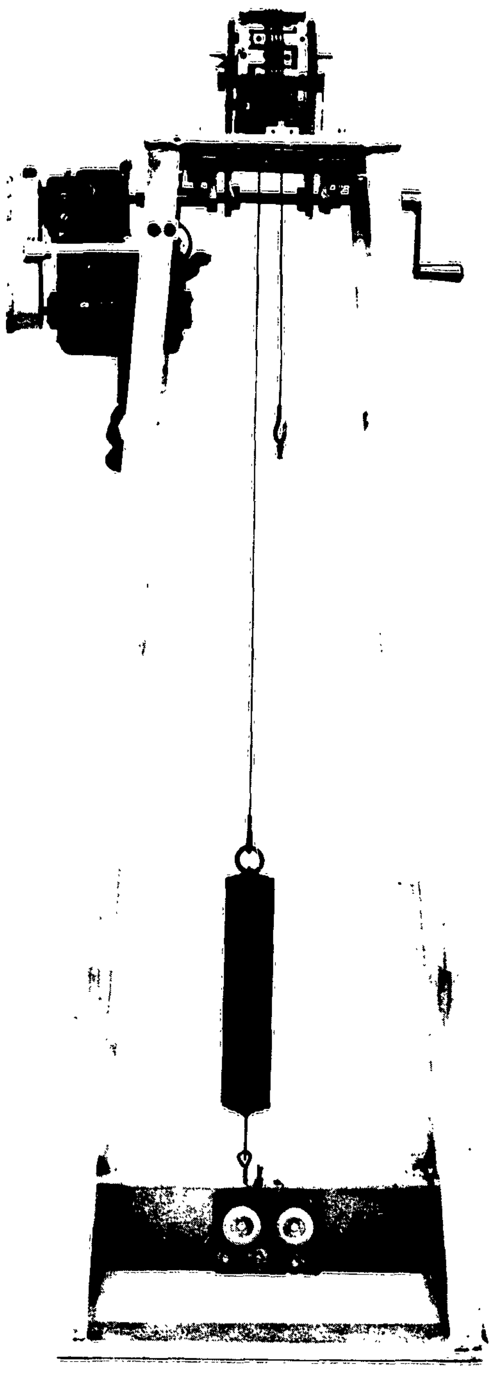


Fig. 7 - Test setup for checking tension ratios

TABLE 1
Results of Tension Test
(Steel Cable on Steel Bar Members)

T_2	T_1	T_1/T_2
3½ Wraps		
1 lb	21 lb	21.0
2 lb	38 lb	19.0
3 lb	64 lb	21.3
4 lb	72 lb	18.0
Average Tension Ratio = 19.9:1		
4½ Wraps		
1 lb	92 lb	92
2 lb	152 lb	76
3 lb	240 lb	80
4 lb	(off scale)	–
Average Tension Ratio = 82.7:1		

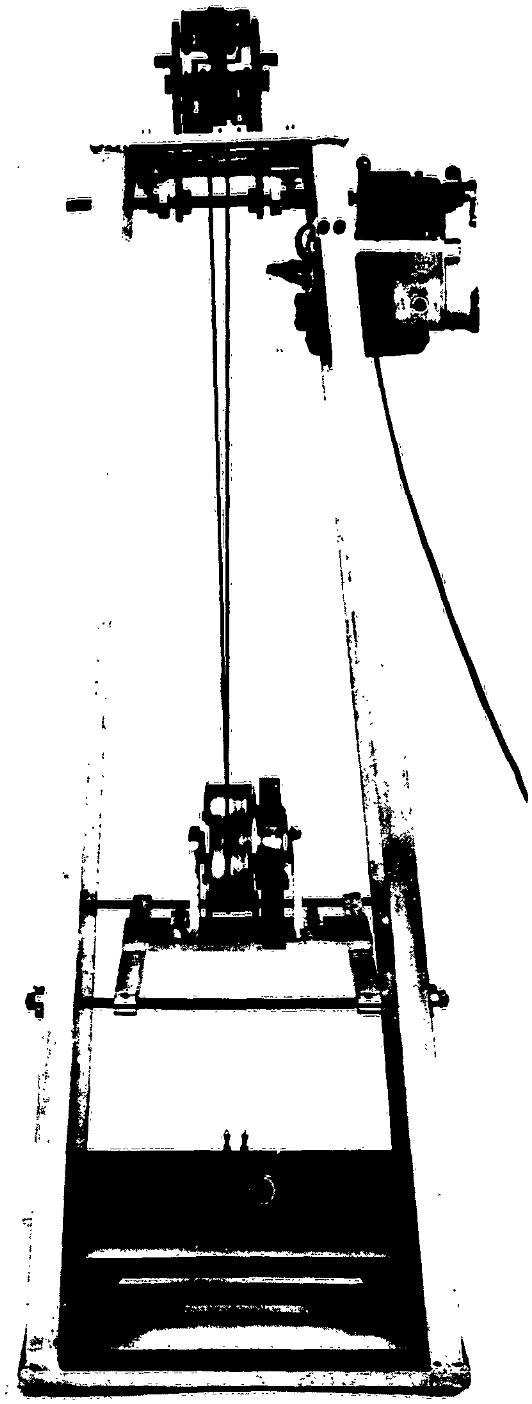


Fig. 8 - Setup for continuous cable operation

CONCLUSION

The idea of using a capstan of this type in the traction unit of a deep-sea hoist seems feasible. Since there is no lateral motion between the bar members and the cable, there is no tendency to twist the cable. In continuous operation under tension, the cable aligns itself on the capstan, and continuously traverses the same path, as shown in Fig. 8.

This capstan works well with many different sizes and shapes of cable. Even faired cable can be wrapped on the capstan, since the cant angle maintains spacing between adjacent wraps without damage to the fairing. Connectors and other similar discontinuities in the cable diameter can also be handled.

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